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THREE DIMENSIONAL MODELLING OF SPILING BOLTS FOR TUNNELLING AT A WEAKNESS ZONE

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Abstract: Spiling bolts are often used as a pre-support measure for tunnelling in an extremely weak rock mass. However, this application is based mainly on experiences without clear description of how spiling bolts work. It may be the first time spiling bolts are modelled using pile elements in FLAC3D. The models are able to describe a more correct picture of the supporting action of spiling bolts by including the bending momentum for the bolts. The models show a great improvement of the roof stability when the bolt ends fixed. Forces and deformation of the bolts are also studied. The models demonstrate the "umbrella" effect of the spiling bolts. The model shows that some input parameters for the "pile elements" spiling bolt are difficult to quantify. These parameters are only possible to obtain by *in situ* tests. References have to be made so that input parameters, to some extent, can be obtained.

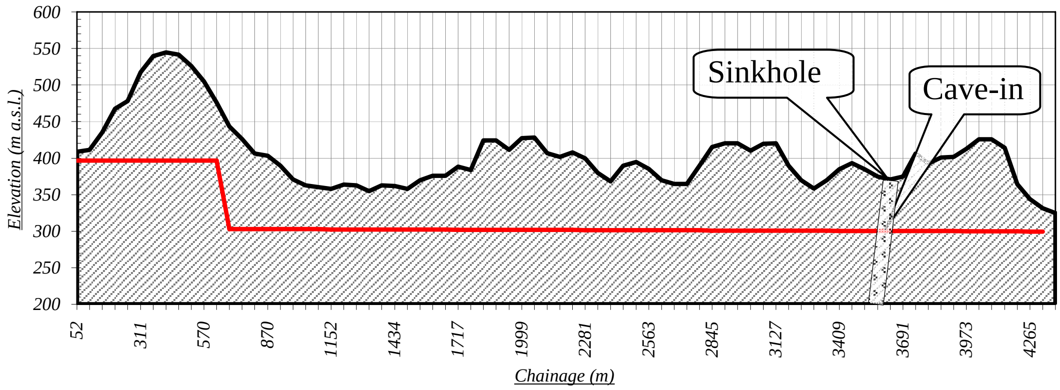
Keywords: weakness zone, cave-in, FLAC3D, pile element, tunnel support, spiling bolts.

1. Background

1.1. *Cave-in Problem*

A serious cave-in problem was encountered in the headrace tunnel of Buon Kuop hydropower project, which is located at the centre part of Vietnam. The longitudinal section and location of the cave-in is presented in Figure 1.

Figure 1: Water conveyance system of Buon Kuop project (PECC2, 2004)



The headrace tunnel consists of two parallel tunnels with 9 m diameter each in young sedimentary rocks. The tunnels are excavated by normal drill and blast method and in different progress. The second tunnel face is about 70 to 100 m lagged behind the first one. Headrace tunnel length is about 4.8 km, and the excavation was carried through three accesses: from intake, from downstream, and at the middle. The cave-in problem happened in the first headrace tunnel at chainage K34+70, where the excavation was progressing from downstream and hit a weakness zone (about 15-20 m wide). Because the drilling equipment was not capable of handling drill rods longer than 6 m, probe drilling was not included in the tunnelling procedure.

After the blasting, the filling material of the weakness zone flowed into the tunnel with water. The movement of the weakness zone material continued all the way 60 m up to the surface and created a sink hole, as shown in Figure 2. The location of the sink hole is indicated in Figure 1.

Figure 2: Cave-in (left) and sinkhole (right) (PECC2, 2004)

Special support measures and excavation method were applied to get through the weakness zone, including spiling bolts, steel ribs, shotcrete and partial face excavation. More details information of the cave-in problem can be found in Trinh (2006).

1.2. *Analyses*

The cave-in problem is analysed by a number of analyses including convergence confinement method (CC-method) and modelling in 2D and 3D. The CC-method was used not only to analyse the cave-in but also for studying rockmass properties. Results from CC-method and 2D models showed that rockmass properties obtained by studying *in situ* rockmass and using the Hoek-Brown failure criterion give the most realistic results. However, the Hoek-Brown failure criterion is not available in FLAC3D-version 2.1. Therefore, to use the FLAC3D models, a series of more complicated analyses are carried out to find the most practical cohesion and friction angle of the rockmass at the weakness zone. A simple criterion for these back analyses is that the model should show the instability at the tunnel face, on the roof and the sinkhole. Results from the back analyses using numerical modelling FLAC3D showed that the cohesion is ranging from 0.05-0.07 MPa, and the friction angle is ranging from 21^o-29^o.

Details of all mentioned analyses can be found in Trinh (2006) or Trinh et al (2006). After the back analyses, the cohesion of 0.05 MPa and the friction angle of 26^o of the rockmass are selected for detailed study the behaviour of the spiling bolts.

2. Spiling Bolt Models

Spiling bolts are often used in tunnelling in extremely poor rock masses. Spiling bolts provide a safe protection ahead of the tunnel face. In spite of their effectiveness and commonly use, spiling bolts are not fully studied today. In this research, spiling bolts are studied in great detail using FLAC3D.

2.1. *Model Selection for Spiling Bolts*

In FLAC3D, there are several types of elements that can be used to model a bolt (Figure 3). These are cable element and pile element. Normally, a radial bolt is often modelled by cable elements, but cable element may not be suited for a spiling bolt due to their differences.

<u>*Cable element:*</u> This element can be imagined as a long steel bar, which can only carry the axial tensile and axial compressive loads (Itasca, 2005). The element has no capability to carry bending

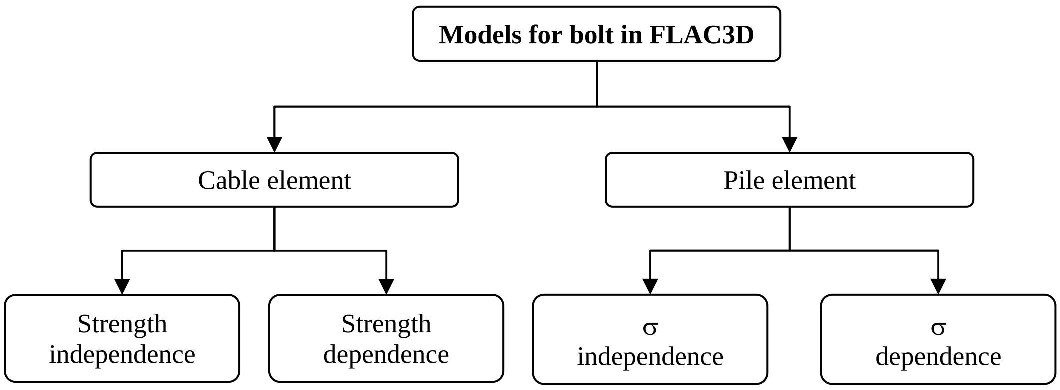
moment. The bearing capacity of this type of element is achieved by the friction between the outer skin of the element and the rock mass and the strength of the element itself.

This type of element is suitable for modelling supports such as anchored cable bolts, radial rock bolts (end anchored or grouted), and pre-tensioned rock bolts. In those bolts, the load bearing is mainly axial.

Pile element: The main difference between cable element and pile element is that the pile element can carry other loads than axial loads. With pile element, loads such as normal to element axis or bending moment can be carried (Itasca, 2005). Pile elements can be used to model bolts that are subjected to complicated loading conditions such as a loading condition of both shear and tension. For example, anchored bolts to prevent the movement of two rock blocks in which bolts have to resist a shearing load and tension. Thus, pile elements can be used to model the spiling bolts because spiling bolts can also be classified as bolts that are working in complicated loading conditions. Spiling bolts are directed approximately parallel to the tunnel axis. Forces on the spiling bolts are friction along the bolts, and also forces acting normal to the bolt axis. The normal forces result in a bending moment in the bolts.

Load bearing capacity of a pile element is provided by the skin friction between the element and rock mass, the strength of the element, the stiffness of the element, and the cross section shape of the element (circular, rectangular, ring).

Figure 3: Options to model bolts in FLAC3D



For both of the elements (cable and pile), there are two types of bolt friction strengths available which are friction strength independent from the confinement and friction strength dependent on the confinement. The independence strength type can be used for such bolts as grouted rock bolts in fractured rock mass, or resin rock bolts. In this situation, the skin friction is decided by how the bolts interact with the rock mass (resin, grouting cement). The second type, strength dependence, is suitable for bolts that require the confinement to develop the friction such as normal grouted rock bolts or Swellex.

In this research, pile element with friction strength dependent on the confinement is selected to model the spiling bolts for tunnelling support at the Buon Kuop weakness zone.

2.2. *Mechanical Properties of Spiling Bolts*

When using pile element to model spiling bolts 13 input parameters are required to define mechanical properties of the bolts (see Table 2). In Table 1, parameters from 1 to 8 can be calculated or obtained without too much effort. Details of the calculation for those parameters can be found in Trinh (2006). The remaining parameters are not easy to define. It may require *in situ* tests to find the true values. In this research, due to limitation of time and finances, *in situ* tests were not carried out. The reference is made to Itasca examples to obtain the values.

Table 1: Bolt properties using pile element

No.	Properties	Unit	Value
1	Young's modulus of the bolts (steel) E	*MPa*	200.10^{3}
2	Poisson's ratio of the bolts (steel) ν		0.25
3	Cross sectional area of the bolts s (ϕ_{out} = 50 mm, ϕ_{in} = 46 mm)	m^2	3.10^{-4}
4	Perimeter of the bolts p (bolt length = 6 m)	*m*	0.16
5	Ultimate tensile strength t	*MN*	0.136
6	Second moment, respect to y-axis of the pile element I_y	m^4	44.10^{-9}
7	Second moment, respect to y-axis of the pile element I_z	m^4	44.10^{-9}
8	Polar moment of inertia J	m^4	87.10^{-9}
9	Shear coupling spring cohesion per unit length	*MN/m*	0
10	Shear coupling spring stiffness per unit length	MN/m^2	10
11	Normal coupling spring cohesion per unit length	*MN/m*	150
12	Normal coupling spring stiffness per unit length	MN/m^2	1000
13	Shear coupling spring friction angle ϕ	*degree*	20

3. Simulation and Behaviour of Spiling Bolts

At the Buon Kuop tunnel, spiling bolts are installed along the roof of the tunnel with a bolt spacing of 30 cm. Bolts are installed after every second excavation round, so the bolts row spacing is 2 m.

Results of bolts deformation and the axial force and bending momentum in the bolts are presented in Figure 4. The results showed large deformations and forces are located at the bolt ends near to the tunnel periphery. This suggests that the bolt ends should be properly supported to improve the effectiveness of spiling bolts.

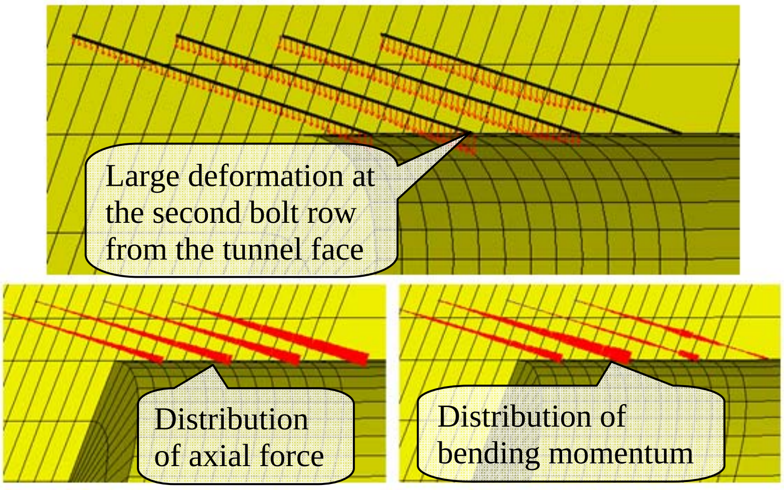


Figure 4: Deformation and forces acting on spiling bolts

With bolt ends are fixed, the model showed a great reduction of the deformation ahead of the tunnel, as shown in Figure 5. As can be seen from the picture, by providing the "bolt ends fix", the deformation ahead of the tunnel reduce from unaceptable level (20-30cm) to the level that ensure the stability for the excavation in the weakness zone (4-6cm). In reality, the spiling bolt ends are often supported by radial bolts, steel ribs or concrete. More information can be found in Hoek (2000), for example.

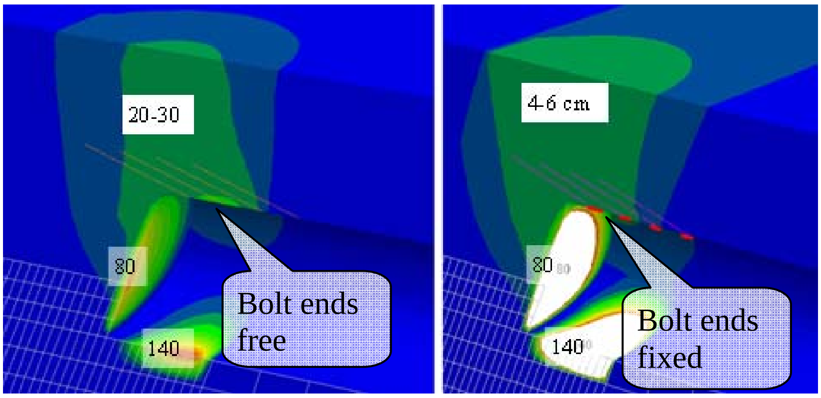


Figure 5: Reduction of the deformation when fixing bolt ends

The role of proper supporting the bolt ends to improve the tunnel stability can be observed in a number of cases in practice.

In figure 6, the spiling bolts were installed in a very poor clay-rich fault zone. The performance of the bolts could be significantly reduced if the bolts were not kept in between the steel ribs. This can be explained by the deformation of the spiling bolts in the above simulations with bolt ends fixed.

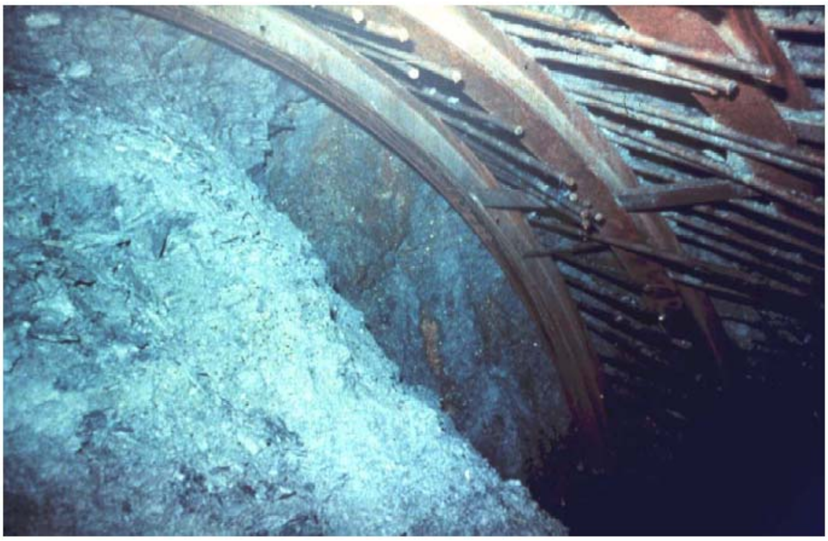


Figure 6: Spiling bolts in very poor clay-rich fault zone (Hoek, 2000)

As can be seen from the picture, by providing the steel ribs to firmly keep the bolts, the spiling bolt system becomes stiffer to some extent beyond the tunnel face, which creates an “umbrella” to protect the roof for the next excavation. This effect and the interaction between bolts and rockmass are probably the fundamental bases for using spiling bolts as a pre-support measure. Results of models without and with the spiling bolts show that without the bolts, the deformation is very large on the roof. With the "umbrella", the large deformation in the roof is prevented. The tunnel floor becomes a releasing face for the deformation, thus large deformation now appear at the floor. However, large deformation at the floor is easier to handle than on the roof by invert concrete arch.

Another issue for spiling bolts is the stiffness of the bolts. In figure 4, it can be seen that there is a significant amount of bending momentum along the bolts, thus the stiffness of the bolts is important. Improper selection of the bolt type may lead to a severe problem. Figure 7 describes a instability situation in a headrace tunnel in Vietnam. As can be seen in this figure, enventhough the spiling bolts are well attached to the steel ribs and shotcrete, but the whole system cannot prevent the cave-in. Reason for this instability is due to too low stiffnes of the spiling bolts.

Figure 7: Spiling bolts are not stiff enough leading to a severe instability

4. Conclusion

The "pile elements" in FLAC3D is a proper model for spiling bolts. With pile element in FLAC3D, one can have a full picture of how spiling bolts work such as the friction between the bolts and rock mass, the contribution of the stiffness of the bolts to control deformation and the “umbrella” effect of the bolts. By including perpendicular load and bending momentum, the pile elements are better than cable elements in describing the working condition of spiling bolts. This useful information is provided in great detail from the 3D simulations. However, *in situ* tests and numerical models should be made to obtain more accurate values of the mentioned spiling bolt properties.

The four input parameters for the spiling bolts are obtained by making references to the Itasca examples. As already discussed, the rock masses in these examples may be different from the rock mass in the Buon Kuop weakness zone. Therefore, the quality of the analyses is reduced to some extent. Possible solutions for this problem are carrying out *in situ* tests or parameter studies for the spiling bolts. In this research, parameter studies for the spiling bolts are not carried out because it requires deformation measurements of the bolts, which were not available, for comparisons.

References

Hoek E., Carlos Carranza – Torres and Brent Corkum (2002). “Hoek – Brown Failure Criterion – 2002 Edition”. Available at http://www.rocscience.com/library/pdf/RL_1.pdf

Hoek E. (2000). “Chapter 12: Tunnels in weak rock”, “Practical Rock Engineering”. Available at http://www.rocscience.com/hoek/pdf/Chapter_12_of_Rock_Engineering.pdf

Itasca (2005). “FLAC3D User’s Manual”. Refer to http://www.itascacg.com/flac3d.html

PECC2 (2004). “Project report - main volume”. Electricity of Vietnam (EVN).

Trinh Q. N. (2006). PhD thesis “Analyses of a cave-in problem in a hydropower tunnel in Vietnam”. Norwegian University of Science and Technology (NTNU), Trondheim, Norway.

Trinh Q.N., Broch E. and Lu M. (2006): “Three-dimensional modelling of a tunnel cave-in and spiling bolt support”, ISRM International Symposium 2006, Singapore.

Trinh Q.N. and Broch E. (2006a): “Analysing a cave-in failure in a tunnel by the convergence-confinement method”, submitted to Rock Mechanics and Rock Engineering.